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CYANOGENESIS IN ANDROPOGON SORGHUM

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INTRODUCTION

It is a prevalent belief among farmers and also among certain writers on the subject of sorghums (*Andropogon sorghum*) that when the sorghum is cut and cured it is no longer poisonous to stock. While this is a strong belief among farmers and is stated as a fact by certain writers and investigators, yet there are other writers and investigators who have claimed that curing has no effect on the power of sorghum to poison stock. In fact, the literature on this subject is quite conflicting in its statements. For instance, Churchill (*3*)[1] states that sorghum is rendered safe for feeding by curing. Turrill (*8*) states that in curing the sorghum is rendered harmless. On the other hand, Schröder and Dammann (*7*) and also Brunnich (*2*) claim that the sorghum is not rendered harmless in the curing process. Furthermore, the well-known fact is recalled in this connection that linseed cake and certain varieties of beans are known to contain hydrocyanic (prussic) acid in the form of glucosid. Peters, Slade, and Avery (*6*) are not sure whether sorghum is rendered suitable for feeding by curing, and stated that the subject should be further investigated.

During this past summer reports came to this Station through the newspapers of several cases of poisoning caused by sorghum which had been cut for some time. This information, the fact that several inquiries were made by farmers as to whether or not it would be safe to feed sorghum which had been cut during dry weather, and the lack of definite information in the literature caused me to take up the present investigation.

There are several questions that should be investigated. The first and probably the most important is to determine whether or not the glucosid is decomposed and the prussic acid liberated when the sorghum is cured; second, to determine whether or not the enzym becomes inactive in the process of curing as claimed by Peters, Slade, and Avery (*6*); third, to determine the effect of the presence of substances such as glucose and

[1] Reference is made by number (italic) to "Literature cited, p. 181."

maltose on the liberation of the hydrocyanic acid from the glucosid; and, fourth, to determine whether or not the hydrocyanic acid may be present in more than one form as has been claimed by Willaman (*10*). While these are the main points studied, there are several others, possibly of minor importance, that were studied.

EXPERIMENTAL WORK

Four different samples of sorghum were used. One was a sample obtained from Mr. Ed. Singleton, of Chickasha, Okla., and was a part of a lot of sorghum which had been cut when it was about 2½ feet high and at a time when there was an extreme drouth in the southwestern part of the State. This was a part of some sorghum which had been fed to 12 head of cattle, 10 of which had died within one hour. This will be called sample 1. Sample 2 was cut at the same stage of growth by Mr. P. A. Gould, of Stillwater, but had not been subjected to as extreme drouth as sample 1, as it was cut at the beginning of the dry weather. Sample 3 was a second-growth sorghum which had grown after heavy rains had fallen and there had been plenty of moisture in the ground all during its growth. This sample was cut fresh each time as it was needed and was about knee-high at the time of cutting. Sample 4 was a volunteer sorghum cut from the Experiment Station farm. This sample was in the dough stage when cut, but it had been subjected to the dry weather of the summer and had grown quite vigorously after the rains had fallen.

The method of determining the hydrocyanic acid was a modification of that used by Viehoever and Johns (*9*) and by Knight (*5*). In the case of the dry samples Nos. 1 and 2, the sorghum was cut into fine pieces and then run through a feed mill. Samples 3 and 4 were cut a little at a time, this part being thoroughly wet and bruised in a large iron mortar. The bruised portions were placed in water in the digestion flask. At first each of these samples were kept in the digestion flask in a water bath at 40° C. for two hours, the apparatus being so arranged that any hydrocyanic acid which passed off would be collected in sodium hydroxide. After this period of digestion the water bath was removed, and 100 cc. were distilled as rapidly as possible, the hydrocyanic acid being collected in sodium hydroxid. It was found by two or three trials that all of the hydrocyanic acid was driven over by distilling 100 cc. At first the distillate was evaporated in vacuum as directed by Viehoever and Johns (*9*), but since this required such a long time it was decided to carry on the evaporation by placing the distillate in a flat-form evaporation dish on a water bath which was heated by an electric hot plate. A current of air from an electric fan at a low speed was directed across the evaporating dish. It was found that under these conditions the solution was usually at about 60° C. and in no case did the temperature go above 70° C. With such an arrangement the evaporation could be made easily within two hours. After the distillate was evaporated almost to

dryness, freshly prepared ferrous sulphate was added and acidified with 30 per cent nitric acid as directed by Viehoever and Johns (*9*). Instead of filtering the Prussian-blue precipitate into a Gooch crucible, as was done by Knight (*5*), it was filtered in the ordinary way and washed thoroughly with dilute nitric acid and then with water. The precipitate and filter paper were then placed in a flat-form platinum dish and heated slowly to dryness in an electric muffle furnace, and then heated strongly to burn the precipitate and oxidize the iron. The dish containing the residue, consisting of the ash of the filter paper and the ferric oxid, was weighed. From the weight of the ferric oxid the amount of hydrocyanic acid was calculated, and from this the percentage of hydrocyanic acid in the dry sorghum. The percentage of moisture in the different samples of sorghum was found by drying at 105° C.

No effort was made to determine whether or not this method would give accurate results, but it was thought that the results would be as accurate as those obtained in using Knight's method (*5*); the colorimetric method of Viehoever and Johns (*9*) and of Francis and Connell (*4*) could not be used, since a colorimeter was not available. Moreover, it was thought that this method would give results sufficiently accurate for comparative purposes.

In order to determine whether or not a part of the hydrocyanic acid was lost in the drying, sample 3 was cut and digested as described above, and then some of it was allowed to dry in the laboratory for 2½ days and was then placed on top of a Freas oven overnight. The temperature on top of this oven was 33° C. A part of this sample was used for the determination of hydrocyanic acid and another for the determination of the water still present.

In order to determine the effect of the rate of drying on the loss of hydrocyanic acid, if any, another part of sample 3 was dried at 50° C. within 24 hours. The results obtained here are given in Table I under experiments 1, 2, and 3.

In order to determine the effect of the presence of glucose and maltose on the liberation of the hydrocyanic acid, portions of sample 2 were digested in a solution containing 1 per cent of dextrose and 1 per cent of maltose. The results of two trials here are given in Table I under experiment 5.

To determine whether or not a part of the hydrocyanic acid existed in the form of nonglucosidic acid, as has been claimed by Willaman (*10*), portions of samples 2 and 3 were digested, and 200 cc. distilled off. Then 50 cc. of 10 per cent sulphuric acid were added to the digestion mixture, which had a volume of about 800 cc., and another 100 cc. was distilled. This last distillate was evaporated, and tests were made for hydrocyanic acid, with negative results, as indicated in Table I under experiment 6.

It has been pointed out by Auld (*1*) that with most feedstuffs digestive conditions would be unfavorable for the action of the enzym on the

glucosid, but he points out very correctly that a slight acidity is the best condition for the action of the enzym and that this acid condition might be found in the paunch of ruminants when certain feedstuffs are used. This being true, it was important to know the acidity of the juice of the sorghum. The juice was pressed from portions of samples 3 and 4, and portions of this juice were diluted very much and titrated with sodium hydroxide, phenolphthalein being used as the indicator. These results are given in Table I under experiment 7. The acids present in samples 1 and 2 were not determined, but it is quite probable that all the acids present were nonvolatile and remained in the dry sorghum. Several other determinations of lesser importance were made, these results being also given in Table I.

TABLE I.—*Results of experiments showing the cyanogenesis in dry and fresh sorghum under various conditions*

Experiment No.	Description of experiment.	Percentage of hydrocyanic acid found.
1a	Sample 3. Digested in water at 40° C. for 1 hour	0.0221
1b	Sample 3. Same as 1a	.0228
2a	Sample 3. Dried for 2½ days in the laboratory, then dried for 16 hours at 33° C	.0050
2b	Sample No. 3. Same as 2a	.0069
3a	Sample 3. Dried at 50° C. for 24 hours. Sample thoroughly dried	.0109
3b	Sample 3. Same as 3a	.0070
4a	Sample 2, plus emulsion digested at 40° for 2 hours	.0222
4b	Sample 2. Same as 4a, except no emulsion present	.0130
4c	Sample 1. Same as 4a	.0514
4d	Sample 1. Same as 4b	.0450
5a	Sample 2 in a solution of 1 per cent of dextrose and 1 per cent of maltose	.0038
5b	Sample 2. Same as 5a	.0059
6a	Sample 3. Digested for 1 hour at 40° C., distilled off 200 cc., then added 10 cc. of 10 per cent sulphuric acid and distilled another 100 cc. Test for hydrocyanic acid in last distillate	None.
6b	Sample 2. Same treatment as 6a	None.
7a	Titrated juice from sample 3. Normality found to be *0.013 N*	
7b	Titrated juice from sample 4. Normality equals *0.0507 N*	
8	Sample 4. Digested for 2 hours at 40° C	.0087
9a	Sample 2. Digested for 2 hours in 5 per cent tartaric acid	.0119
9b	Sample 1. Treatment same as 9a	.0018
9c	Sample 3. Treatment same as 9a, except sample was ground under 5 per cent tartaric acid	None.
10a	Sample 3. Kept at 40° C. for 15 minutes	.0281
10b	Sample 2. Same treatment as 10a	.0177
11a	Sample 2. Treated with water at 80° C. and kept at this temperature for 1 hour	.049
11b	Sample 2. Treated with water at 90° C. and kept at this temperature for 1 hour	.0040
12a	Sample 2. Kept in air bath at 70° C. for 1 hour	.0124
12b	Sample 2. Kept in air bath at 115° C. for 1 hour and 30 minutes	.0087
13a	Sample 1. Kept for 1 hour in *N/100* sodium hydroxid made acid and distilled	.0220
13b	Sample 3. Kept in solution of sodium hydroxid (*N/100*) for 1 hour	.0051
13c	Sample 3. Treatment same as 13b, except the sodium hydroxid was *N/50*, and the solution was made slightly acid with tartaric acid and kept for 1 hour at 40° C	.0136

DISCUSSION OF RESULTS

Any discussion of the experimental results will necessarily be of the nature of a summary. A comparison of the percentage of hydrocyanic acid found in experiments 1a and 1b with those in 2a and 2b shows that approximately three-fourths of the acid is set free in the process of drying. This goes to confirm the common belief that sorghum is safe for feeding after it has been dried. At the same time the results show that not all of the hydrocyanic acid disappears. A comparison of experiments 2a and 2b with 3a and 3b shows that the rapidity with which the sorghum is dried determines the percentage of the hydrocynaic acid that is retained by it. This point is of considerable importance in Oklahoma on account of the fact that farmers quite frequently cut their sorghum during drouths after it has been partially dried while yet standing; and after it is cut, being already partly dry, it dries very quickly. Under such conditions a large percentage of the hydrocyanic acid would be retained in the fodder. Sample 1 was cut under such conditions.

A glance at experiments 4, a, b, c, and d, will show that the enzym which is present in the sorghum is still active and that the addition of emulsin does not cause the hydrocyanic acid to be liberated in greater quantity.

A comparison of the amount of hydrocyanic acid found in experiments 5a and 5b with experiment 4 shows that the addition of such a small quantity as 1 per cent of dextrose and 1 per cent of maltose seems to hold back or prevent the liberation of about three-fourths of the acid. This is an extremely important result from the practical standpoint. Dextrose and maltose were selected because of the fact that they are formed by the action of the pytalin on the starches in the paunch. This retention of the hydrocyanic acid in the presence of these sugars may be assumed to be due either to a reaction between the sugars (aldehydes) and hydrocyanic acid or to a lessening of the activity of the enzym by the sugars. This would lead to the suggestion that in case there is any doubt about the poisonous nature of the sorghum one should feed some concentrate before feeding the sorghum. In this way a considerable quantity of dextrose and maltose would be produced by the salivary digestion and would tend to prevent liberation of the hydrocyanic acid of the sorghum which is fed afterwards. At the time of this experiment I had not read Peters, Slade, and Avery's work (6), in which they showed that it was possible to give very large doses of hydrocyanic acid without any harmful effects provided at the same time a somewhat proportionate amount of dextrose was given.

It has been claimed by Willaman, as has already been stated, that the hydrocyanic acid exists in the sorghum in two forms—glucosidic and nonglucosidic. It seems natural to suppose that the nonglucosidic acid would not be liberated under the conditions that existed in my

work, that is the digestion was carried on in a very faintly acid solution, the acidity being due to the acids present in the sorghum. If this assumption is made, the results in experiments 6a and 6b seem to show that no nonglucosidic hydrocyanic acid exists in the sorghum. Of course it is possible that the nonglucosidic acid was distilled over in the first 100 cc., but this would not be in harmony with Willaman's supposition that it is the hydrocyanic acid that is obtained in 5 per cent of tartaric distillation that causes the poisonous effect and which is a nonglucosidic acid. Furthermore, the fact that no acid was found in the distillate from sample 3 when it was ground under 5 per cent of tartaric acid and distilled from the acid solution shows that nonglucosidic acid is not present.

The results in experiments 9a and 9b show that when a dry sorghum is digested with 5 per cent of tartaric acid a considerable percentage of the hydrocyanic acid is not liberated, and when this is taken in connection with experiment 9c, one may conclude that the water was absorbed by the dry substance more rapidly than was the acid and that some hydrocyanic acid was set free before the acid came in contact with the glucosid.

It is seen from the acid concentrations as found in experiments 7a and 7b that the contents of the paunch would be faintly acid in reaction when the green or the dry sorghum is eaten. It might be argued that the acidity would be neutralized by the alkalinity of the saliva; but when the acidity as found here is compared with the alkalinity of the saliva it is seen that, when the alkalinity of the saliva is taken into account, and assuming a normal saliva flow, the contents of the paunch would still be slightly acid, a condition most favorable for enzym action. This acid condition would exist until rumination talkes place, when the acid would be neutralized.

A comparison of the results of experiment 10a and 10b with that of experiment 1 shows that all the hydrocyanic acid is liberated within the first 15 minutes of the digestion.

Willaman and West (*11*) and other investigators have shown that hydrocyanic acid gradually disappears from sorghum during its growth, so that but little is present in the mature plant. It was thought that this might not be true if large amounts of the acid had been formed as a consequence of dry weather, in the sorghum at some stage of growth. Sample 4 had been stunted by dry weather, but it is seen from experiment 8 that nearly all of the hydrocyanic acid had disappeared. The percentage of hydrocyanic acid found in this sample should be compared with that of sample 1, which was doubtless greater still before the sample was dried.

No discussion is needed of the experiments 11 to 13b, inclusive. The reason for making experiment 13c, was that it was thought that possibly as shown in my work, the enzym is rendered practically inactive by dilute alkaline solution, and it might be that the hydrocyanic acid would not

be liberated on this account in the paunch; but when it later entered the true stomach, where the solution would become slightly acid, the hydrocyanic acid would be set free. The result under experiment 13c seems to show that this is true. Digestion first with *N/100* sodium hydroxid, as shown in experiment 13b, prevents the liberation of the hydrocyanic acid. Certainly, then, digestion with *N/50* sodium hydroxid would prevent the liberation of this acid, and yet it is seen by acidifying this solution and allowing further digestion that more than one-half of the hydrocyanic acid was given off.

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EFFECT OF CERTAIN COMPOUNDS OF BARIUM AND STRONTIUM ON THE GROWTH OF PLANTS

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INTRODUCTION

Although it has been known for more than a century that plants are able to extract appreciable amounts of the relatively insoluble compounds of barium contained in soils, very little scientific investigation has been made to determine whether or not the compounds of this element have any specific function in the vegetable economy. Because compounds of barium are poisonous when taken into the animal body, there appears to be a general impression that these compounds would exert a similar influence upon plants.

In a former investigation [1] the writer has shown that small amounts of barium can be readily detected and determined quantitatively in the ash of tobacco, corn, potatoes, and a number of other plants grown under normal conditions in the field. Since soils contain only very small amounts of barium, necessarily in the form of relatively insoluble compounds, it is a question of considerable scientific interest how and why it is that notable amounts of this element are absorbed and apparently assimilated by plants, under normal conditions of growth. The object of the present investigation was to determine the effect of some of the well-known compounds of barium and of the closely related metal, strontium, upon the growth of plants.

EXPERIMENTAL WORK

Preliminary experiments consisted in growing plants in nutrient solutions to which were added certain compounds of barium, soluble as well as insoluble. It soon developed that plants could be grown in a nutrient solution containing moderate amounts of barium nitrate or carbonate, whereas an equal amount of the chlorid or sulphate produced a decided toxic effect. After having determined that the plants selected for the water-culture experiments were tolerant of barium carbonate and nitrate, it was decided that a method more nearly approximating the normal conditions under which plants are grown would be a better procedure. Accordingly the plan was adopted of growing the plants in barium-free sand contained in earthenware pots to which the necessary basal plant-food ration could be added, together with the desired compounds of barium.

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COWPEAS

In the first series of experiments twelve 1-gallon earthenware jars were filled with a clean quartz sand that contained very little plant food. To each of the pots of sand was added the following basal plant-food ration: 10 gm. of calcium carbonate, 10 gm. of tricalcium phosphate, 5 gm. of magnesium carbonate, 4 gm. of potassium nitrate, 2 gm. of potassium chlorid, and 2 gm. of sodium thiosulphate. In addition to this plant food, varying amounts of barium carbonate were added to all the pots except the first, which served as a check against any other one pot in this series of experiments. Cowpeas (*Vigna sinensis*) were planted in the sand in the pots, and during the time the plants were making their growth the sand was kept moist with clear hydrant water. Previous to starting the experiment, 100 liters of hydrant water were evaporated to dryness and the residue thus obtained examined for barium, but none was found. In another experment 25 liters of water flowing from the drain tiles on the Experiment Station farm were collected and evaporated. The residue thus obtained was examined for barium compounds, but none were found.

The cowpea plants were allowed to grow until they were about 10 to 12 inches tall. They were then taken up in such manner as to preserve the roots intact, and the adhering sand was washed off as well as possible. The photograph reproduced in Plate 24, A, was taken two weeks after planting; that shown as figure B, after the plants were removed from the sand in which they grew.

Table I shows the amount of barium carbonate added to each pot and also the weight of the air-dry plants that grew in each of the pots.

TABLE I.—*Effect of barium carbonate upon the growth of cowpeas—First series*

Pot. No.	Quantity of barium carbonate added to soil.	Weight of 10 air-dried plants.	Pot No.	Quantity of barium carbonate added to soil.	Weight of 10 air-dried plants.
	Gm.	*Gm.*		*Gm.*	*Gm.*
1 (control)	None.	9.15	7	5	11.40
2	0.5	12.00	8	6	10.90
3	1	11.20	9	8	11.15
4	2	10.15	10	10	10.80
5	3	9.50	11 [a]	5	....
6	4	10.55	12	5	11.65

[a] This pot received no calcium carbonate, and all the plants died.

From the results obtained in this experiment it is to be observed that there were appreciable increases in the yields of all the plants grown in the presence of barium carbonate and calcium carbonate over that of the control pot. In the absence of calcium carbonate,

however, the action of the barium carbonate was strongly toxic, as shown by the failure of the plants in pot 11.

The effect of the barium compound upon the growth of the cowpeas is more strikingly shown in Plate 24. In figure A the pot on the right is the control, which received no barium compound. The pot in the middle received the same plant food as the control and 10 gm. of barium carbonate in addition. The pot on the left received 5 gm. of barium carbonate, but no calcium carbonate. It received the same amount of tricalcium phosphate as the other pots. One object in mind in this experiment was to ascertain whether there would be a tendency on the part of the plants in this pot to substitute barium for calcium in their growth. The peas germinated and came through the sand, made a stunted growth for a few weeks, and then died. The difference in the growth of the plants in the pot in the center and the one on the left shows very strikingly the toxic effect of barium carbonate in the absence of calcium carbonate. This experiment affords a very striking example in the plants in the center pot of the protective action of calcium carbonate on plants when grown in the presence of a toxic substance.

Figure B of Plate 24 shows the effect of barium carbonate on the growth of the roots of the cowpea plants grown in pots 1, 2, and 8; the plants on the right were the control and received no barium carbonate, the plants in the center received 0.5 gm. of barium carbonate, and plants on the left received 6 gm. of barium carbonate. It will be observed that the plants which grew in the presence of barium carbonate have made a markedly increased root growth over the control. It is also to be borne in mind that the plants in the center received only 0.5 gm. of the barium compound, whereas the ones on the left received 6 gm. or 12 times as much as the former, thus indicating that a very small amount of barium carbonate produces as great effect on the root growth as much larger amounts.

The compounds of strontium have many chemical and physical properties similar to those of barium and calcium. It was thought that a few comparative experiments showing what effect like compounds of barium and strontium might have upon the growth of plants would be of some interest in this connection. Therefore in the series of experiments that follow plants have been grown in the presence of both barium and strontium compounds and compared with similar plants grown in the presence of calcium compounds.

OATS

In a second series of experiments oats (*Avena sativa*) were grown in sand under conditions similar to those in which the cowpeas were grown in the previous experiment, with the same basal plant food ration as before.

After the young oat plants had reached a height of about 10 inches they were thinned to the same number of plants in each pot and as near equal in size as possible. The oats were brought to maturity and harvested and, after thoroughly air-drying, the grain was threshed and the weights of the air-dry grain and straw produced in each pot were determined. There were two control pots in this experiment, and the average weight of the grain and the straw from these two pots was taken as a check against other pots receiving compounds of barium or strontium in this series.

TABLE II.—*Effect of certain barium and strontium compounds upon the growth of oats—Second series*

Pot No. and treatment.	Weight of grain.	Gain or loss in weight of grain over control.	Weight of straw.	Gain or loss in weight of straw over control.
	Gm.	*Gm.*	*Gm.*	
Control pot 1	19.25	....	39.25	....
Control pot 2	17.40	....	34.50	....
Average	18.33	....	36.88	....
Pot 3+2 gm. of barium carbonate	18.50	+0.17	40.00	+ 3.12
Pot 4+5 gm. of barium carbonate	20.65	+2.32	44.75	+ 7.87
Pot 5+2 gm. of strontium carbonate	18.40	+ .07	37.15	+ .27
Pot 6+5 gm. of strontium carbonate	21.10	+2.77	46.25	+ 9.37
Pot 7+2 gm. of barium carbonate and 2 gm. of strontium carbonate	16.50	−1.83	37.25	+ .37
Pot 8+5 gm. of barium sulphate	11.00	−7.33	24.75	−12.13

TABLE III.—*Comparison of weight and percentage of nitrogen, phosphorus, and potassium per pot—Second series*

Pot No. and treatment.	Nitrogen.		Phosphorus.		Potassium.	
	Gm.	*Per cent.*	*Gm.*	*Per cent.*	*Gm.*	*Per cent.*
Control	0.3217	1.755	0.0752	0.41	0.0522	.285
Pot 3+2 gm. of barium carbonate	.3608	1.95	.0777	.42	.0518	.28
Pot 4+5 gm. of barium carbonate	.4120	2.00	.0847	.41	.0599	.29
Pot 5+2 gm of strontium carbonate	.3367	1.83	.0773	.42	.0534	.29
Pot 6+5 gm. of strontium carbonate	.4579	2.17	.0886	.42	.0570	.27
Pot 7+2 gm. of barium carbonate+2 gm. of strontium carbonate	.2739	1.66	.0644	.39	.0429	.26
Pot 8+5 gm. of barium sulphate	.1727	1.57	.0418	.38	.0286	.26

In Table II is given the amount of barium or strontium compounds added to each pot, and the air-dry weights of the grain and the straw produced in each of the experiments. Table III gives a partial analysis

of the grain showing the important constituents contained in the grain produced in each experiment.

Both barium carbonate and strontium carbonate have increased the percentage of nitrogen as well as the total weight of nitrogen when applied separately. Applied together, there is diminution. Barium sulphate has diminished both percentage and total weight of nitrogen.

The weights of grain and straw produced in this series of experiments show increased yields in all pots receiving either barium carbonate or strontium carbonate separately. The pot in which there was a mixture of the two carbonates shows a decrease in the yield of grain, while the yield of the straw is practically the same as that of the control. In the pot receiving barium sulphate there is a very marked decrease in both the grain and the straw, which shows the toxic effect of this compound when compared with the carbonate.

The analysis of the grain produced in each of the pots for nitrogen, phosphorus, and potassium shows a slightly greater content of each of these elements where there was an increase in the yields of the plants over that contained in the control. The last two pots in the series, No. 7 and 8, show a marked falling off in their nitrogen, phosphorus, and potassium content when compared with the controls and the other pots in this series. The maximum increase in protein—that is, $N \times 6.25$—amounts to 2.60 per cent over that of the control, and the grain containing it was grown in the presence of 5 gm. of strontium carbonate. The next highest result was obtained where 5 gm. of barium carbonate were present. The phosphorus and potassium content appears to be less affected by barium and strontium compounds than does nitrogen.

SPRING WHEAT

In the third set of experiments spring wheat (*Triticum aestivum*) was sown in pots containing sand to which was added the same basal plant-food ration as that added to the pots in the experiments with cowpeas and oats. The quantities of barium and strontium compounds added are given in Table IV. In addition to the barium and strontium carbonates certain pots received small amounts of what was claimed to be a very active commercial radio-active fertilizer. The amount of this material added to each pot is given in Table IV and is in accordance with the recommendations of the company marketing this material. After the young plants had reached a height of 6 or 8 inches, they were thinned to the same number of plants in each pot and were brought to a state approaching maturity. Unfortunately, when the wheat grains were in the dough stage, a careless attendant left the ventilators of the greenhouse open over Sunday and the sparrows came in and consumed a part of the grain growing in each pot; hence, the results for the grain in this series of experiments were discarded. The straw was allowed to ripen

and was harvested. When thoroughly air-dried it was weighed. The results appear in Table IV.

TABLE IV.—*Effect of barium carbonate and strontium carbonate on the growth of wheat—Third series*

Pot No. and treatment.	Weight of dry straw.		Gain or loss over control.
	Observed.	Average.	
	Gm.	*Gm.*	*Gm.*
Pot 1 (control), no barium added	41.15	40.95	....
Pot 2 (control), no barium added	40.75		
Pot 3+2 gm. of barium carbonate	34.25	34.25	−6.70
Pot 4+2 gm. of barium carbonate	34.25		
Pot 5+2 gm. of strontium carbonate	38.50	38.12	−2.83
Pot 6+2 gm. of strontium carbonate	37.75		
Pot 7+2 gm. of barium carbonate+2 gm. of strontium carbonate	32.25	34.00	−6.95
Pot 8+2 gm. of barium carbonate+2 gm. of strontium carbonate	35.75		
Pot 9+2 gm. of barium carbonate+0.7 gm. of radio-active material	37.75	37.25	−3.70
Pot 10+2 gm. of barium carbonate+0.7 of gm. radio-active material	36.75		
Pot 11+0.7 gm. of radio-active material alone	37.35	36.67	−4.28
Pot 12+0.7 gm. of radio-active material alone	36.00		

The results in this series of experiments show a loss in the weight of the straw over the average weight of the straw in the control pots; however, the greater loss occurs in the barium pots. The strontium pots show a loss of one-half of that of the barium pots.

The radio-active fertilizer, when used alone or in combination with barium carbonate, did not affect the yield of the straw greatly, the yield in each case being less than that of the control.

WINTER WHEAT

In a fourth series of experiments winter wheat was sown in pots of sand containing the same basal plant-food ration as in previous experiments. Strontium nitrate was the compound subjected to experimentation in this series. The amounts added are given in Table V, which also gives the yields and average weight of the grains of wheat produced in in each experiment.

The results obtained in this series of experiments show abnormal yields in both grain and straw which probably are due to the large amounts of nitrate radical present rather than to the strontium ion, since strontium carbonate has in no instance given such marked increase in yields.

TABLE V.—*Effect of strontium nitrate on the growth of winter wheat. Fourth series*

Pot No. and treatment.	Number of grains per pot.	Weight of grain per pot.	Average weight per grain.	Weight of straw.
		Gm.	Gm.	Gm.
Pot 1 (control), no strontium nitrate	372	8.8872	0.0239	34.50
Pot 2 (control), no strontium nitrate	292	7.7050	.0266	27.50
Average	332	8.3201	.0252	31.00
Pot 3+5 gm. of strontium nitrate	369	11.9005	.0323	44.50
Pot 4+5 gm. of strontium nitrate	555	19.6108	.0353	52.00
Average	462	15.7586	.0338	48.25
Pot 5+10 gm. of strontium nitrate	561	17.6505	.03146	62.00

The results obtained in the analysis of the grain for nitrogen, protein, phosphorus, and potassium are interesting (Table VI). It will be seen that with the addition of strontium nitrate there is a decided increase in the nitrogen content of the grain and a decrease in the phosphorus, while the potassium content remains practically constant.

TABLE VI.—*Percentage of nitrogen, protein, phosphorus, and potassium contained in the grain produced in each of the foregoing experiments*

Pot No.	Nitrogen.	Protein (N × 6.25).	Phosphorus.	Potassium.
Pot 1 (control)	1.68	10.50	0.36	0.18
Pot 2 (control)	1.71	10.68	.35	.24
Average	1.695	10.59	.355	.21
Pot 3	2.77	17.31	.22	.22
Pot 4	2.73	17.06	.23	.18
Pot 5	3.00	18.75	.23	.21

Having obtained unusual results in the yields and in the nitrogen content of the grain in the previous series of experiments, another, the fifth, series of pot experiments, similar to the ones that have been described, was carried out. This series was planned as a further check on the effect of strontium carbonate on the growth and the nitrogen content of wheat. The amount of strontium carbonate added to each pot and the yields of grain and straw produced are given in Table VII.

The seeds in pots 9 and 10 came up, and the stunted plants struggled for existence for the greater part of the time the other plants in this series were making a complete growth. The plants never reached a height of more than 10 inches, thus showing that strontium can not replace calcium in the growth of plants.

TABLE VII.—*Effect of strontium carbonate on the growth of wheat—Fifth series*

Pot No. and treatment.	Weight of grain.	Weight of straw.	Gain or loss in—	
			Grain.	Straw.
	Gm.	*Gm.*	*Gm.*	*Gm.*
Pot 1 (control)	10.00	36.50		
Pot 2 (control)	9.00	34.50		
Average	9.50	35.50		
Pot 3+5 gm. of strontium carbonate	9.00	42.00		
Pot 4+5 gm. of strontium carbonate	10.50	40.00		
Average	9.75	41.00	+0.25	+5.50
Pot 5+10 gm. of strontium carbonate	11.50	39.50		
Pot 6+10 gm. of strontium carbonate	13.00	40.00		
Average	12.25	39.75	+2.75	+4.25
Pot 7+20 gm. of strontium carbonate	9.50	36.00		
Pot 8+20 gm. of strontium carbonate	10.00	35.50		
Average	9.75	35.75	+ .25	+ .25
Pot 9+10 gm. of strontium carbonate, no calcium carbonate	None.	([a])		
Pot 10+10 gm. of strontium carbonate, no calcium carbonate				

[a] Not weighed.

The results in the fifth series of experiments agree very closely with those of the other experiments in which strontium carbonate was used, both with respect to yields and the results obtained in the analyses of the grain (Table VIII). They also show conclusively that the increased yields obtained in the fourth series of experiments in which strontium nitrate was used were due to the greater amounts of nitrate being present which was assimilated and thus produced grains of wheat that contained 8 per cent more protein than was found in the control experiments, which showed a protein content equivalent to that of wheat grown under normal conditions.

The last two experiments in the fifth series show conclusively that strontium will not replace calcium in the growth of plants. They also show, however, that strontium carbonate in the absence of calcium carbonate is apparently less toxic towards plants than barium carbonate in the absence of calcium carbonate. It will be recalled that in the first series of experiments, in which an attempt was made to grow cowpeas in the presence of barium carbonate without calcium carbonate, all the plants died soon after coming through the sand, whereas in the case of the wheat plants in the presence of strontium carbonate and the absence of calcium carbonate the plants did not die soon after they

were up, but maintained a struggling existence during the greater part of the time other plants in the series were making a normal growth, thus indicating that strontium carbonate is less toxic in the absence of calcium carbonate than barium carbonate.

TABLE VIII.—*Percentage of nitrogen, protein, phosphorus, and potassium in the grain grown in the pots in the fifth series of experiments*

Pot No. and treatment.	Nitrogen.	Protein (N×6.25).	Phosphorus.	Potassium.
Pot 1 (control)	1.69	10.56	0.31	0.20
Pot 2 (control)	1.66	10.38	.27	.18
Average	1.68	10.47	.29	.19
Pot 3	1.68	10.50	.33	.19
Pot 4	1.79	11.10	.35	.19
Average	1.74	10.80	.34	.19
Pot 5	1.61	10.00	.27	.19
Pot 6	1.69	10.56	.31	.17
Average	1.65	10.31	.29	.18
Pot 7	1.64	10.25	.27	.19
Pot 8	1.68	10.50	.31	.20
Average	1.66	10.38	.29	.19

CORN

In a sixth series of experiments corn plants (*Zea mays*) were grown in pots of sand containing the usual basal plant-food ration. To these pots were added varying amounts of barium and strontium compounds as shown in Table IX. Three corn plants were allowed to grow in each pot until the plants had tasseled and bloomed. As was to be expected, the corn plants were dwarfed on account of greenhouse conditions, the plants reaching a height of about 3 feet. After making their maximum growth the stalks were cut from the roots at the top of the sand. The fodder was stripped from the stalks. The roots were taken up and washed as free from adhering sand as possible. The different parts into which the plants were divided were kept separate, and after thoroughly air-drying, the weight of each of the parts determined and from thence the air-dry weights of the entire plants were computed. These results are given in Table IX.

The results in this series of experiments agree in a general way with those obtained in previous experiments with wheat and oats, where the same compounds of barium and strontium have been applied in equal quantities and under similar conditions.

TABLE IX.—*Air-dry weights of the corn plants in each of the experiments*

Pot No. and treatment.	Air-dry weights.				Gain or loss in weight when compared with the controls.			
	Roots.	Stalks.	Fodder.	Entire plants.	Roots.	Stalks.	Fodder.	Entire plant.
	Gm.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*
Pot 1 (control)	11.50	13.25	17.60	42.35				
Pot 2 (control)	8.00	10.30	15.35	33.65				
Average	9.75	11.77	16.47	38.00				
Pot 3+2 gm. of barium carbonate	10.65	14.25	18.75	43.65				
Pot 4+2 gm. of barium carbonate	12.10	8.25	19.30	39.65				
Average	11.38	11.25	19.02	41.65	+1.63	−0.52	+2.55	+3.65
Pot 5+2 gm. of strontium carbonate	13.00	15.80	23.50	52.30				
Pot 6+2 gm. of strontium carbonate	11.75	14.50	20.80	47.05				
Average	12.38	15.15	22.15	49.68	+2.63	+3.38	+5.68	+11.68
Pot 7+2 gm. of barium carbonate and 2 gm. of strontium carbonate	14.75	13.00	20.25	48.00	+5.00	+1.23	+3.78	+10.00
Pot 8+2 gm. of barium nitrate	11.50	13.25	18.75	43.50	+1.75	+1.48	+2.28	+ 5.50
Pot 9+5 gm. of barium sulphate	10.75	8.00	14.25	33.00	+1.00	−3.77	−2.22	− 5.00
Pot 10+2 gm. of barium chlorid	11.50	7.50	19.25	38.25	+1.75	−4.27	+2.78	+ 0.25
Pot 11+5 gm. of barium carbonate	13.5	12.00	20.00	45.50	+3.75	+ .23	+3.53	+ 7.50
Pot 12+5 gm. of strontium carbonate	13.2	14.5	20.7	48.40	+3.45	+2.73	+4.23	+10.40

It will be noted again that the maximum increase in yield occurred in the presence of strontium carbonate, while equal amounts of barium carbonate produced only a very slight increase in the yield of the entire plants.

It is interesting to note that all of the roots in the corn experiment show some increase in yield over that of the controls, while in the weight for the stalks there are an equal number of minus and plus differences. In the weights of the fodders there is only one experiment in which the fodder produced is less than the control. In the weights for the entire plants barium sulphate gave a very decided negative difference. Both the sulphate and the chlorid reduced the yields in the stalks very decidedly.

TABLE X.—*Analyses of the corn fodder from the preceding experiments*

[The results are expressed as percentage of the moisture-free substance]

Pot No. and treatment.	Crude ash.	Insoluble residue (silica, etc.).	Ferric oxid (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).
Composite sample from pots 1 and 2 (control)	9.71	1.15	[a]0.44	1.03	0.92	3.22
Pots 3 and 4+2 gm. of barium carbonate	9.66	.84	.39	.89	.49	3.88
Pots 5 and 6+2 gm. of strontium carbonate	9.15	.91	.60	.92	.56	3.50
Pot 7+2 gm. of barium carbonate and 2 gm. of strontium carbonate	10.20	1.01	.44	1.00	.67	3.92
Pot 8+2 gm. of barium nitrate	9.15	1.14	.26	1.14	.67	3.61
Pot 9+5 gm. of barium sulphate	10.54	1.38	.58	1.34	.82	3.96
Pot 10+2 gm. of barium chlorid	11.07	1.21	.73	1.30	.58	3.91
Pot 11+5 gm. of barium carbonate	12.10	1.23	.83	.90	.60	4.34
Pot 12+5 gm. of strontium carbonate	9.53	.78	.14	.90	.50	3.86

[a] The irregularities occuring in the iron determinations are probably due to iron-oxid scales which may have come from the paint on the mill hopper, as some such scales were observed in some of the samples.

TABLE X.—*Analyses of the corn fodder from the preceding experiments*—Continued.

Pot No. and treatment.	Soda (Na_2O).	Barium sulphate ($BaSO_4$).	Strontium sulphate ($SrSO_4$).	Phosphorus pentoxid (P_2O_5).	Nitrogen (N).	Protein (N×6.25).
Composite sample from pots 1 and 2 (control)	0.86	....	....	0.22	1.16	7.25
Pots 3 and 4+2 gm. of barium carbonate	.72	.059	....	.225	.96	6.01
Pots 5 and 6+2 gm. of strontium carbonate	.43	....	.15	.24	.81	5.06
Pot 7+2 gm. of barium carbonate and 2 gm. of strontium carbonate	.18	.055	.16	.22	.93	5.81
Pot 8+2 gm. of barium nitrate	.29	.044	....	.27	1.47	9.17
Pot 9+5 gm. of barium sulphate	.24	....	....	.32	1.44	9.00
Pot 10+2 gm. of barium chlorid	.24	Tr.	....	.28	.98	6.06
Pot 11+5 gm. of barium carbonate	.23	.02	....	.28	1.63	10.02
Pot 12+5 gm. of strontium carbonate	.37	....	.20	.17	.93	5.84

The results of the analyses of the fodders that were produced in each of the experiments show no very striking differences in the mineral composition of the fodders in any of the experiments (Table X).

It will be observed that only very small amounts of barium and strontium have been taken up by the plants growing in the presence of compounds of each of these elements.

SOYBEAN

In Plate 24, C, are shown four jars of soybean (*Soja max*) plants that were grown in cultural solutions. The plants in the jars on each end have been grown in a cultural solution containing no barium compound, whereas the two pots in the center have been grown in a similar solution containing barium nitrate. The plants in the two jars in the center received their sulphur from a solution containing taurin, while the plants in the end jars received their sulphur from a solution of magnesium and potassium sulphates. The differences to be observed in the growth of the two sets of plants is attributed to the presence of the barium nitrate which appears to have retarded the growth of the roots, stems, and foliage of the two sets of plants in the center.

When the very small amounts of the barium compounds that occur in the soil and the relatively insoluble state in which they occur are taken into consideration, one is led to wonder how it is that plants are able to extract even as much barium as can be determined in the ash of normal plants. Since no barium was found by careful examination of the residue from the evaporation of 25 liters of water flowing from a tile drain on the Station farm, although the presence of barium in the soil of the area drained had been proved by extracting 0.0508 gm. of barium sulphate from the hydrochloric-acid solution from 500 gm. of an average sample representing the first foot of soil from this field, it would appear that the roots of plants do not obtain their barium from the percolating soil water, but rather by some kind of selective

action upon the soil particles. A determination of total barium in the soil of another field near by gave 0.08 per cent of barium sulphate, obtained by decomposing the soil with hydrofluoric and sulphuric acids.

CONCLUSIONS

From the results obtained in the different series of experiments in this investigation the following conclusions are drawn.

(1) Barium compounds in the absence of calcium carbonate are poisonous to plants; but barium carbonate in the presence of an excess of calcium carbonate apparently exerts a distinct stimulating influence on the growth of the plants studied.

(2) There is no tendency for barium to replace calcium in the growth of plants when calcium carbonate is omitted from a plant-food ration under the conditions of these experiments.

(3) Strontium compounds have in most instances given larger increased yields than barium compounds.

(4) Strontium carbonate can not be substituted for calcium carbonate in the growth of plants under the conditions studied, though strontium carbonate is less toxic to plants in the absence of calcium carbonate than barium carbonate.

(5) Neither barium nor strontium compounds can be looked upon as important plant foods, although the presence of small amounts of the carbonate of each of these elements has given increased yields that are noteworthy in most instances.

(6) Barium and strontium carbonates accelerated the growth of the roots of such plants as were examined.

(7) Increasing the amount of strontium nitrate gave a corresponding increase in the nitrogen content of wheat.

(8) No barium compounds were found in the residue obtained upon evaporating 25 liters of drainage water collected from the drain tiles on the Station farm, which would indicate that the barium found in plants is taken up in place by the plant roots.

PLATE 24

A.—Effect of barium on the growth of cowpeas with and without calcium carbonate.

B.—Stimulating effect of barium on root growth of cowpeas.

C.—Effect of barium on the growth of soybeans.


A
B
C

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